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THE DESIGN AND OPERATION OF A STIFF TRIAXIAL ASSEMBLY FOR POST FAILURE ROCK PROPERTY TESTING

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by

B. Gorski*

SUMMARY

The equipment described in this report has been used successfully in tests with cylindrical rock core to develop the following, stress-strain data for individual specimens:

1. Prefailure, peak, postfailure and residual strength.
2. Multiple failure state triaxial peaks including their respective residual strengths at corresponding confining pressures (complete Mohr circle analysis).

The equipment was designed and built as an add-on feature for an existing compression testing machine.

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INTRODUCTION

BASIS FOR DESIGN

The determination of complete force-deformation behaviour of mine pillars is time consuming and expensive. It is viable, therefore, to examine the behaviour of laboratory specimens under similar loading conditions. In order to study behaviour beyond the peak compressive axial load, the conventional soft compression machine must be replaced by a loading system stiff enough to prevent the commonly observed explosive failure of rock specimens. If the results of such tests are to be used for actual design criteria then the strength of the specimens (model pillars) must be related to the strength of the prototype pillar underground and the post-failure characteristics of the laboratory specimens must be the same as those of the mine pillars which they are to model.

Rock types have been divided into two classes (Class I and Class II), depending on their stress-strain behavior in the post failure region when uniaxially loaded (1). Class I behaviour is characterized by 'stable' fracture propagation, in the sense that work must be done on the sample to effect further reduction in load-carrying ability. Hence rocks that exhibit Class I behaviour retain some strength even after the compressive strength has been exceeded. Class II rock behaviour is self-sustaining, i.e., the elastic strain energy stored in the sample when the applied stress equals the compressvie strength is sufficient to maintain fracture propagation until the specimen has lost virtually all strength. Fracture can be arrested only if strain energy is extracted from the test piece during fracture propagation. Obviously, Class II failure behaviour cannot be established by way of stiffening the testing machine alone because fracture would proceed even if the machine stiffness were infinite. However, Class II behaviour in rock exhibit brittle to ductile transition in the triaxial loading state and are fully ductile at some value of confining pressure.

The evaluation and proposed adaptation of equipment and development of testing procedures to meet analytic requirements concerning post-failure rock deformational proportions are described by Gyenge (2).

In this report, the experimental techniques, testing procedures, and special equipment designed for determining the complete stress-strain behavior of BX cores of both hard and soft rocks are described. The method of

testing involves the loading of rock specimens in parallel with pre-engineered schnorr disc springs (3) in a medium-capacity testing machine. The method of increasing the press longitudinal stiffness is detailed. Experimental data showing the complete stress-strain behaviour of a selected brittle rock type is presented.

Initially brief descriptions of equipment in the CANMET Rock Mechanics Laboratory will be given including modifications undertaken and further material acquisitions as required to carry out the proposed stiff testing program from sample prep to test data retrieval inclusive.

SAMPLE PREPARATION

A homogeneous diabase slab from a Quebec quarry 15 cm thick was selected to provide test specimens in the stiff testing program. A "IBARMIA" drill press equipped with a water swivel (Fig. 1) was used to drill BX diameter cores. The rock core was cut to specimen length using a "Clipper" cut-off saw (new acquisition) equipped with a 355 mm diamond blade and water coolant (Fig. 2). The specimens were axial lapped to within 0.25 mm deviation of constant diameter with a "Spittire" roller lapper (Fig. 3) using 240 silicon carbide slurry grit as the grinding medium. Initially the weight of the sample was used to propogate the axial grinding with the roller lapper. Since then the author has modified the equipment by adding the upper roller guided by two posts that imposes 15 kg force on the sample thereby considerably reducing sample prep time and elimination of manual force application methods. Extensive diameter reduction is accomplished using a 10" utilathe (Fig. 4). Once axial lapped the core stick must be end lapped to the following tolerances (4):

1. Ends parallel to within 0.025 mm.
2. Ends square to length within 0.025 mm.
3. Length to within 0.025 mm of specified exact length for stiff testing.

Initially samples were end lapped to the above requirements using a steel lapping jig (Fig. 5) machined to the same specified tolerances. With the sample fixed in the jig and both ends protruding above the steel faces, the sample was prepared by manually grinding down the core stick one end at a time in a figure "8" motion on a rotating lapping wheel (Fig. 6a) surface wet-

ted with water-slurried 240 silicon carbide grit. When the core stick end faces were ground flush with the steel jig faces (as indicated by grinding off of "magic marker" radial marks on the steel faces) the sample was considered prepared to the afore mentioned tolerances. Having realized how time consuming this procedure is along with the physical effort required in carrying out this method of preparation the author has designed a "double lapper" (Fig. 6b) to circumvent in part this onerous task. The "double lapper" has been fabricated and is now in use in our laboratory and has proven to satisfy the following objectives as originally envisioned;

1. To lap samples varying from 25 mm to 55 mm in diameter.
2. To lap samples varying from 10 mm to 180 mm in height.
3. To lap one or two core sticks simultaneously to identical tolerances.
4. To lap the ends of samples parallel and square to the axis to within 0.012 mm.
5. To lap samples down in height at a rate of approximately 0.1 mm/min.

The "double lapper" (Fig. 7) is powered by an electric motor having a 3-speed 'V' belt drive coupled to a gear reducer. The other end of the 'V' belt drives a shaft coupled by sprocket and sprocket chains which in turn drive the three main shafts that transmit rotation to the core sticks in addition to driving the grinding plates. The upper grinding plate is adjustable vertically to accommodate varying sample heights and weight reduction on core sticks is accomplished by two adjustable tension springs. Different sample diameters are accommodated by roller sleeves.

With the above system the operator need only to insert the core sticks, turn the "double lapper" on, manually apply a water slurry silicon carbide grit to the cast iron grinding plates and set the timer to a time corresponding to the reduction in sample height required (a surface grinder on order will be modified to prepare samples of any shape, i.e., cubes).

Following end lapping the core sticks are washed clean with water, air blown dry and checked for tolerances using a dial gauge and surface plate (Fig. 8). Upon tolerance confirmation the core sticks are oven dried in a vacuum oven (Fig. 9) set at a heating rate of less than 1°C/min to a maximum of 50°C (5). Upon drying the core sticks are weighed (Fig. 10) to within 0.01 g and measured to within 0.025 mm in height and in diameter. The samples are then stored in a desiccator (Fig. 11).

STRAIN GAUGE INSTALLATION

Samples selected for determination of Young's Modulus and Poisson's ratio are strain gauged as a means to monitor rock deformation during testing. The procedure used comprises the following:

1. Ensuring the rock specimen is dry.
2. Pencil scribe circumferential line at mid height.
3. Pencil scribe four axial lines spaced at 90° around the circumference of the sample.
4. Sanding rock surfaces at the four proposed strain gauge locations at mid height.
5. Cleaning the prepared surfaces with acetone and kim wipes.
6. Select four strain gauges having identical gauge factors and check for circuitry faults using an ohmmeter.
7. Mount the strain gauges to the rock sample one at a time using a polyester base quick hardening cement. Cover the strain gauge with cellulose and press gauge into place using thumb pressure and aligning gauge with the pencil scribed lines. Apply clamping pressure of 4 kg to the gauge for 15 minutes using a rubber compression block.
8. Apply two axial gauges at mid height 180° apart circumferentially and the same for two diametric gauges at right angles to the axial orientation (Fig. 12).
9. Solder lead wire to the axial gauges completing a series circuit and the same for the diametric gauges. Check the circuitry for "shorts".

The rock specimens are now considered fully prepared and ready for testing. The report will now consider the mechanical and electronic set-up for post failure testing in the triaxial state.

TRIAXIAL STIFF TESTING SET-UP

The requirements for the triaxial stiff testing set-up comprise the following:

1. Compression testing machine.
2. Triaxial chamber.
3. Confining pressure panel-digital indicator/analog output.

4. Strain indicators - analog output to recorders.
5. Load cell.
6. Displacement transducers - analog output.
7. Parallel stiffening element.
8. Stiffening element support system.

The requirements have been met and are detailed as follows.

1. THE COMPRESSION MACHINE

A Tinius Olsen 1300 kN triple range soft compression machine (Fig. 13) was used to apply axial loads. The compression machine has a transducer analog output circuit compatible to X-Y recorders. For this test program an automatic interrupt was incorporated. Depending on how long an electric release button was pushed, the press servo-pump would be interrupted during a loading cycle. Pushing this button immediately unloads the rock sample (used for Class II behaviour). The amount of unloading is governed by how long the release button is pushed in.

The stiffness of the steel elements of the hydraulic press was estimated by loading a strain gauged steel specimen and measuring its deformation and the movement of the press bed (Fig. 14). By subtracting the steel specimen deformation from the press bed displacement, the net press displacement is obtained. Figure 15 depicts the press stiffness at a fixed crosshead height. Increasing the crosshead height decreases the stiffness. The reduction in stiffness due to the volume of compressed hydraulic fluid acting on the press bed piston was calculated based on the cross-sectional area of the piston and a fluid height of 12.7 mm. The computed press stiffness is less than 0.53 MN/mm.

2. THE TRIAXIAL CHAMBER

A 'BX' size Hoek triaxial cell (new acquisition) (Fig. 16) was selected as the confinement pressure apparatus. This apparatus has desirable features as follows:

a) quick-release hydraulic oil coupling
b) air bleeder valve
c) reusable urethane jackets
D) strain gauged rock samples can be accommodated.

The Hoek cell is equipped with a pair of two-piece spherical seated hardened platens (Fig. 17). The spherical seats are incorporated to accommodate non paralleled sample end faces. However, as rock specimens are prepared with end faces parallel, spherical seats are not required (6). The spherical seats have since been replaced with one-piece paralleled end platens. These platens will increase the stiffness of the assembly by the elimination of four "mating" surfaces.

Major disadvantages observed in Hoek cell construction especially in the post failure region of rock testing are as follows:

a) The single wedge sheared tips of the sample deform in an axial direction past the outer edge of the platen (Fig. 18) resulting in instantaneous high deformation and a reduction in cross-sectional area resisting axial load. Mine pillars do not exhibit this failure mode.

b) The urethane jacket imposes an elastic confinement to the sample in addition to that maintained by the hydraulic confinement pressure panel during post failure rock dilation.

c) Whereas axial rock deformation can be measured by $LVDT_s$, diametric measurements are not physically possible during post failure testing.

An 'NX' size Hoek cell has been ordered and once modified will have the following features over the 'BX' Hoek cell:

a) 'BX' size samples may be accommodated by using a spacer jacket (Fig. 19). With 'NX' size platens bearing on a 'BX' size rock sample, shear tip axial slippage will be circumvented.

b) The spacer jacket will protect strain gauges permanently mounted on the inside of the 'NX' urethane jacket. These strain gauges will be calibrated to monitor urethane jacket confinement pressure effects and sample diametric strain (7).

Figure 20 depicts calibration of a urethane jacket subjected to internal water pressure. The calibration curve is shown in Fig. 21. Using an 11 cc displacement stroke confinement pressure generator connected to a calibrated counter, total sample dilation data was retrieved during a multi stage stiff triaxial test with the sample subjected to a confinement pressure of 17 MPa. The calculated circumferential strain for this sample is depicted in Fig. 21 with the corresponding urethane jacket confinement imposed. In this

case the jacket confinement imposed is minimal. However, during low confining pressure stiff testing, this effect will increase.

3. CONFINING PRESSURE PANEL

The confining pressure panel (Fig. 22) is capable of generating confinement pressures up to 205 MPa. The panel incorporates the following features:

a) A 1cc displacement "Enerpac" hand jack

b) a 11cc displacement stroke pressure generator (new acquisition) connected to a flex cable counter calibrated at 0.013 cc displacement per count registered. This unit is used to maintain constant confining pressure and also to monitor the volumetric strain of the rock sample.

c) A Heise 1 to 300 MPa pressure dial gauge

d) A 'SNC' air operated 'Enerpac' intensifier

e) a Heise (new acquisition) digital transducer pressure indicator for pressures up to 205 MPa equipped with a 0 to 10 volt analog output op- tion. The analog output is connected to an X-Y recorder to retrieve axial load versus confinement pressure data.

4. STRAIN INDICATORS

Four Bruel and Kjaer type 1526 strain indicators (new acquisitions) having 0-10 volt analog output (Fig. 23) monitor the following strains during stiff triaxial testing:

a) Axial rock specimen strain-two SR-4 strain gauges in series with a 'dummy' arm to complete a half bridge configuration.

b) Diametrical rock specimen strain-same configuration as item a.

c) Strain gauged load cell calibrated in kN/$\mu\varepsilon$.

d) Strain gauged urethane jacket calibrated in MPa/$\mu\varepsilon$ to monitor rock specimen diametric strain in the post failure region and confinement pressure imposed by the urethane jacket.

All of the above strain readings are recorded on X-Y recorders

5. LOAD CELL

The load cell consists of a hardened right solid steel cylinder (Fig. 24) strain-gauged in a full bridge configuration. Strain versus press load

readings are used for calibration purposes. Spacer platens accommodate different disc spring stacked height.

6. DISPLACEMENT TRANSDUCERS

Two Hewlett-Packard 7DCDT-10 cc displacement transducers (Fig. 25) were acquired to measure post failure axial rock specimen deformation. The transducers are small displacement LVDTs in the order of 30 VDC/inch. The power source consisted of two independent Moxon Inc. 0 to 25 VDC power supplies. By varying the voltage input to the transducers separately, both LVDTs were calibrated to identical mv/inch ranges. This facilitated a self averaging series output circuit from the LVDTs to an X-Y recorder. The transducers are mounted externally to the Hoek cell platens by clamping ring arms.

7. PARALLEL STIFFENING ELEMENT

Schnorr disc springs (Fig. 26) are used in different combinations in parallel with the test specimen for different stiffnesses and ranges of deformations. Six 200 mm x 112 mm x 16 mm schnorr disc springs were acquired and when series stacked gave the load/deformation characteristics as depicted in Fig. 27. The descrepancy between theoretical and actual spring stiffness for the springs is attributed to steel support indentation effects. As the steel support and the springs act in series, indentation strain energy replaces the amount of spring stiffness lost. Consideration has been given to replacing steel components (E = 200 GPa) where applicable with sintered tungsten carbide (E = 600 GPa) and in this way reduce indentation effects by a factor of three (8).

Disc springs when under load in the compression machine continuously level the flex head thereby ensuring the load cell aligns with longitudinal axis of the sample regardless of sample failure mode.

By perusal of Fig. 27 the following may be concluded;

a) The sample and platens are stiffer than the press.

b) The platens are stiffer than the sample near peak strength. Upon failure at peak strength the sample is further deformed by 0.55 mm due to platen/load cell strain energy release. The press automatic unload is used to halt this deformation. Shorter platens and load cell in the 'NX' triaxial stiff test assembly will be used to reduce the effects of this strain energy release.

c) The six disc springs increase in stiffness with increasing deflection.

By predeflecting the disc springs the press is made stiffer than the platen/sample assembly. However, in the present design, predeflection reduces usable press load. Figure 28 depicts the stiff assembly design proposed for a 18 MN compression machine. This assembly incorporates predeflection of the disc springs as proposed for the 'NX' stiff assembly.

8. SUPPORT SYSTEM

The assembled stiff support system is detailed in Fig. 29. The support assembly provides the following functions:

a) support and house the BX Hoek cell
b) provide clearance for the LVDT arms
c) house the load cell and platens
d) support the disc springs.

The assembly can be readily adapted to uniaxial tests by removing the Hoek cell. This uniaxial set-up replaces the original stiff uniaxial test prototype as depicted in Fig. 30.

The assemblies as depicted in Fig. 29 and 30 were designed, drafted and constructed by CANMET personnel.

9. 'BX' OPERATIONAL TEST SET-UP

Figure 31 shows the triaxial setup for a stiff loadng test. The letters on the figure denote the individual components as follows:

A - Disc springs
B - Support assembly
C - LVDT
D - LVDT power supplies
E - Compression machine
F - Strain indicator - axial deformation
G - Strain indicator - diametric deformation
H - X Y_1 Y_2 recorder - axial load vs sample deformation
I - Strain indicator - load cell
J - X Y_1 Y_2 recorder - axial load vs LVDT post failure
K - Confinement pressure digital indicator
L - Intensifier control
M - 11 cc calibrated pressure generator

N - X Y recorder - axial load vs confinement pressure

O - Automatic press unload switch.

TYPICAL TEST DATA

Figure 32 depicts the force-displacement relationship for a 'BX' size diabase rock specimen prepared to a 2 to 1 ratio. The figure represents typical data for one rock specimen retrieved in a multiple failure state stiff triaxial test. Figure 32 letters denote the following:

A - G	Prefailure region
B	peak at σ_3 = 0.34 MPa
C	peak at σ_3 = 3.45 MPa
D	peak at σ_3 = 6.90 MPa
E	peak at σ_3 = 10.34 MPa
F	peak at σ_3 = 13.79 MPa
G	peak at σ_3 = 17.24 MPa
G - I	post failure region
H - I	residual strength at σ_3 = 17.24 MPa
I - J	At constant load σ_3 is gradually reduced to zero to correlate stress vs confinement pressure (plotted simultaneously on another X-Y recorder), with the corresponding residual strengths in region I - J for any given confinement pressure.

Complete Mohr's circle analysis for this rock specimen is displayed in the upper right hand graph.

SUMMARY AND CONCLUSIONS

To date, diabase 'BX' size rock core have been tested using the disc spring stiff assembly and multiple failure state stiff triaxial tests have been carried out. The results of such tests correlate with conventional test methods carried out on the same host rock. Additional improvements can be seen to consist of: built-in spring deflection; reduction in platen/assembly height; elimination of spherical seats and replacement of steel components with sintered tungsten carbide where applicable.

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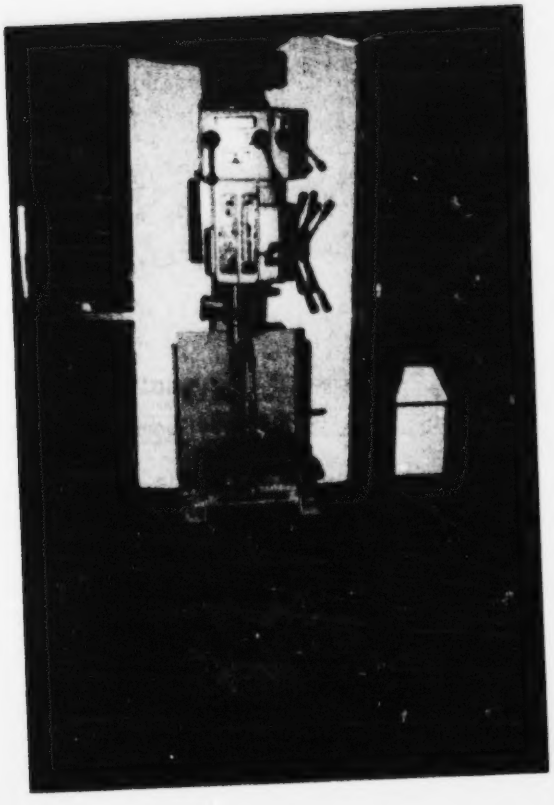


Fig. 1 - Drill press for coring samples.

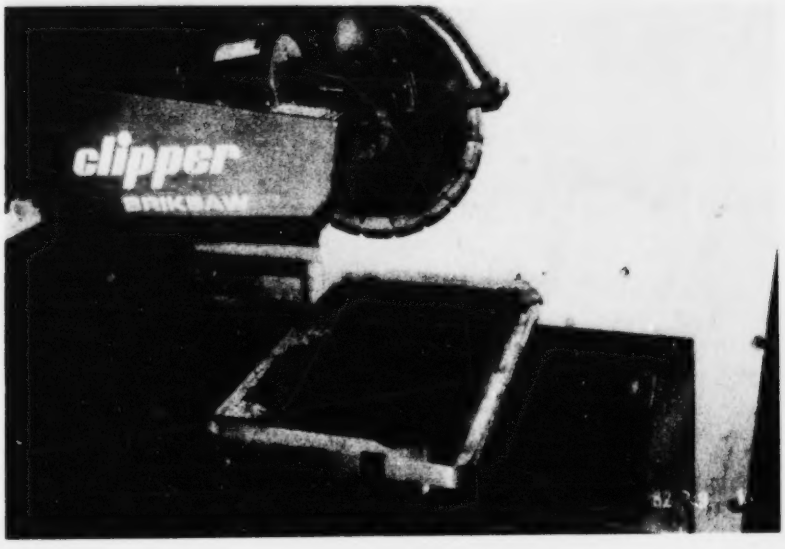


Fig. 2 - Diamond saw for trimming samples.

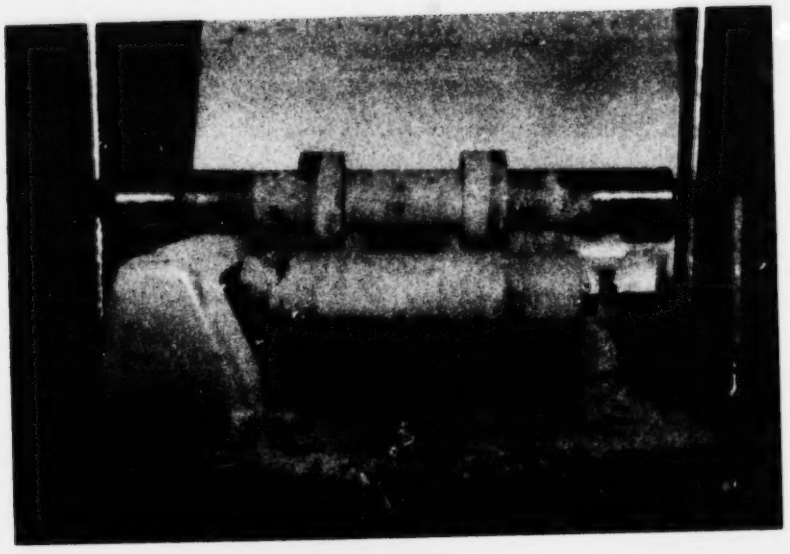


Fig. 3 - Roller lapper for axial sample trimming.

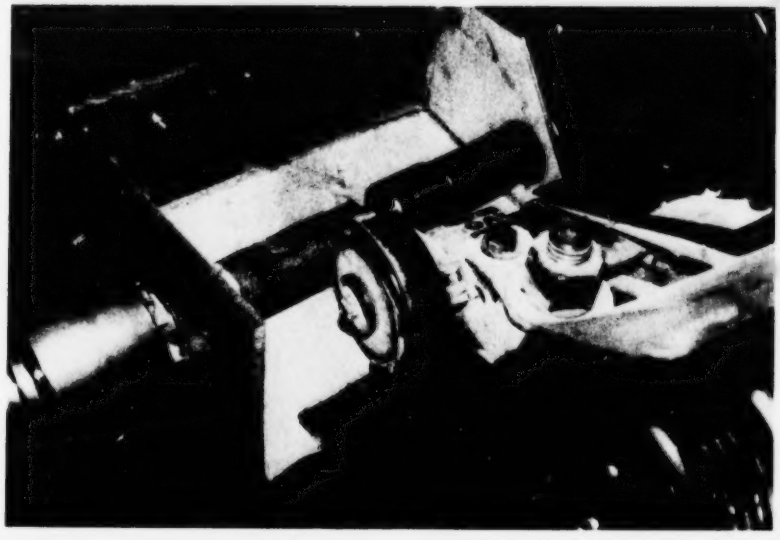


Fig. 4 - Lathe for extensive axial sample trimming.

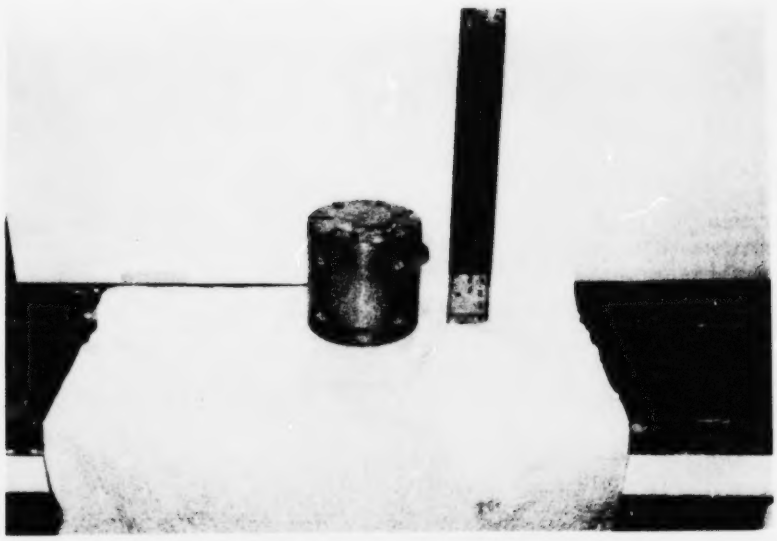


Fig. 5 - Lapping jig for samples.

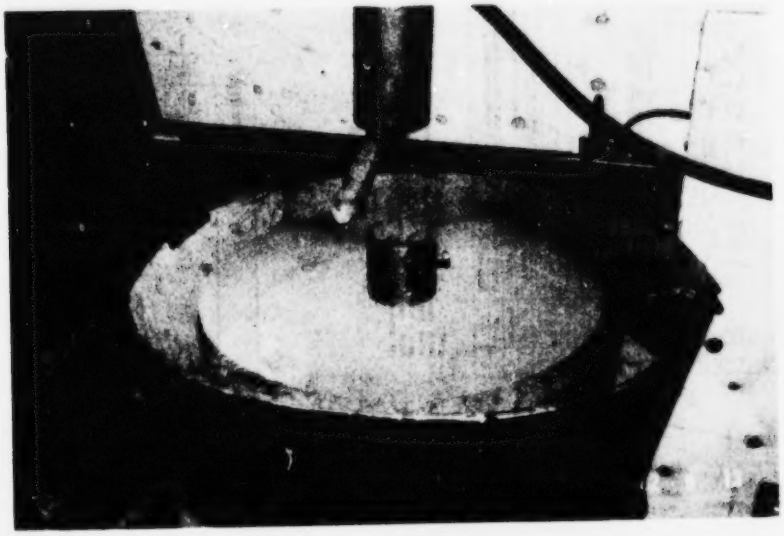


Fig. 6 - a) Lapping wheel.

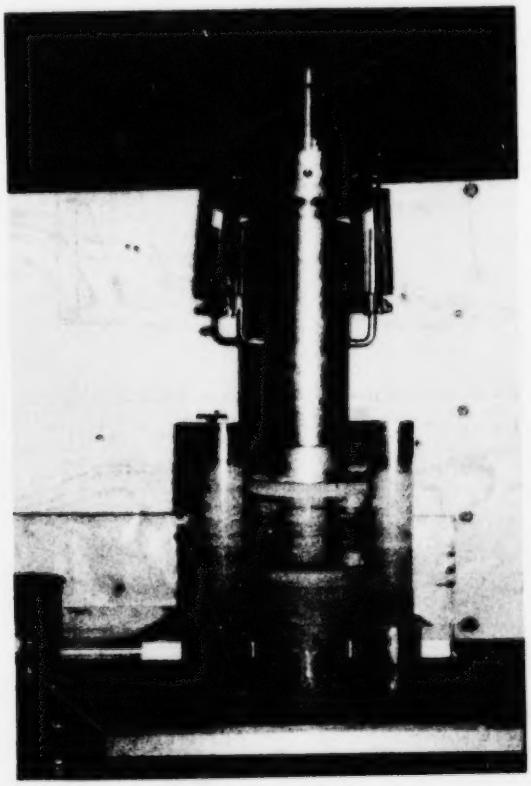


Fig. 6 - b) Double lapper.

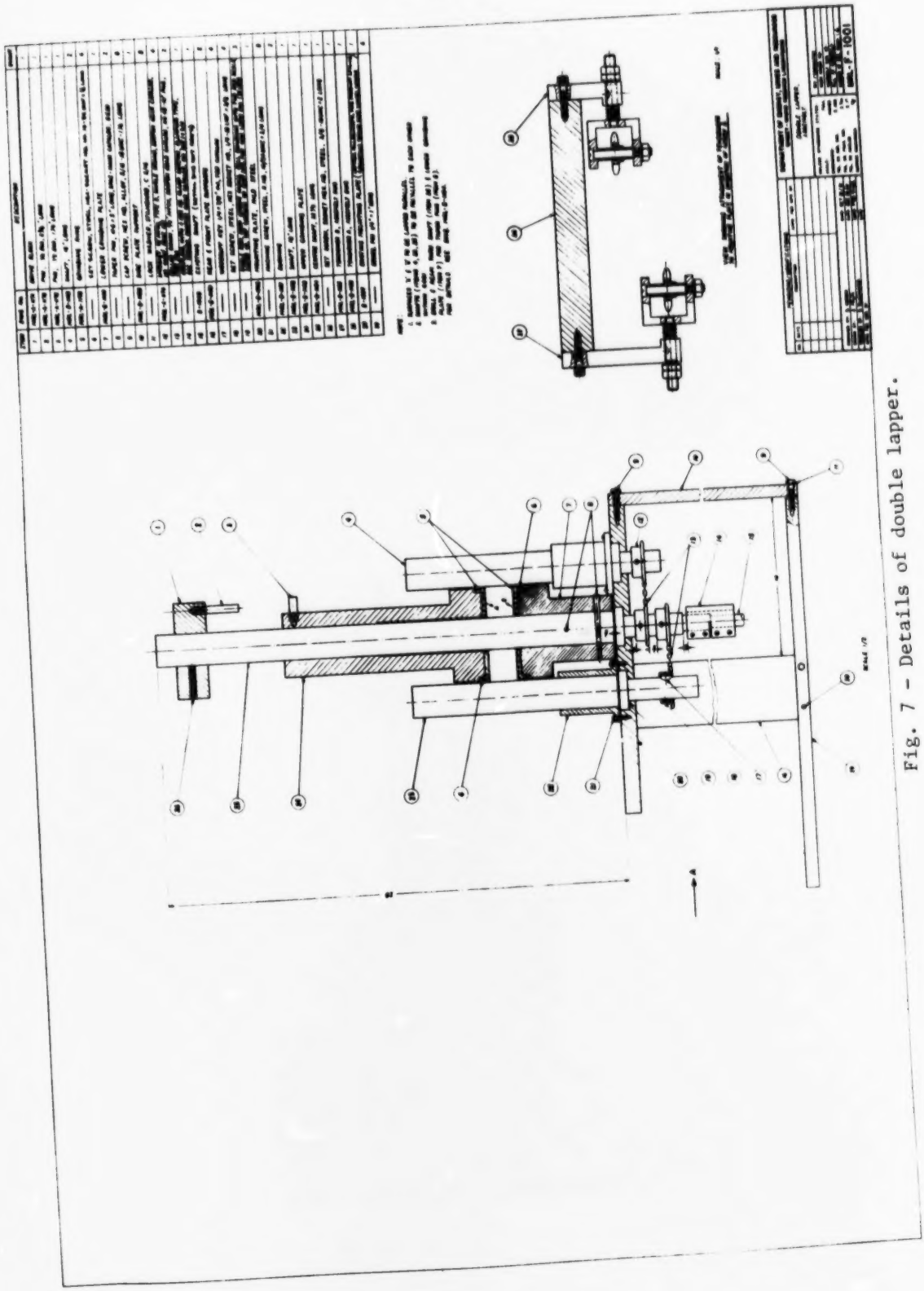


Fig. 7 - Details of double lapper.

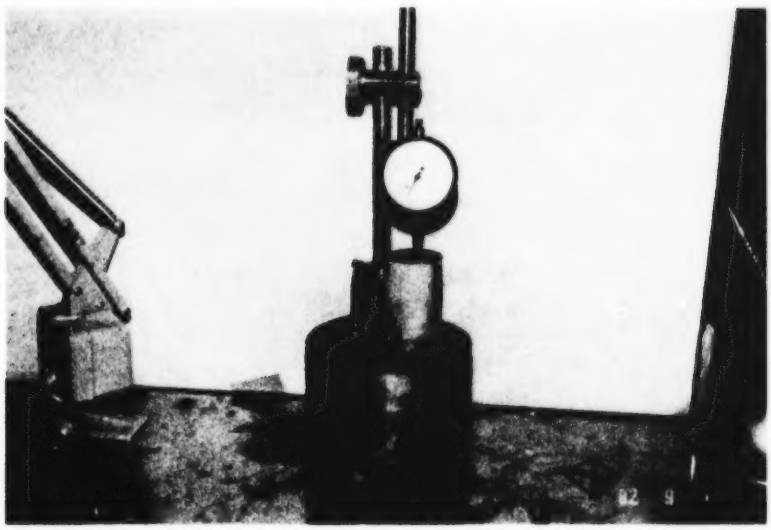


Fig. 8 - Dial gauge/surface plate.

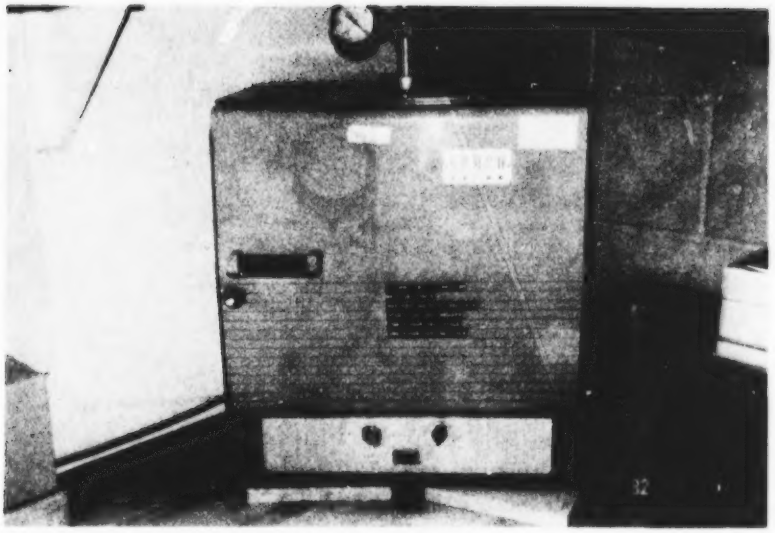


Fig. 9 - Vacuum oven.

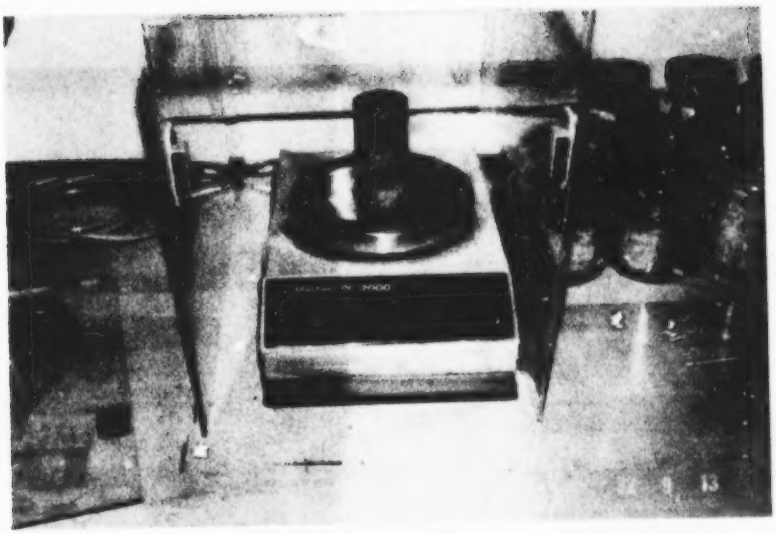


Fig. 10 - Mettler scale.

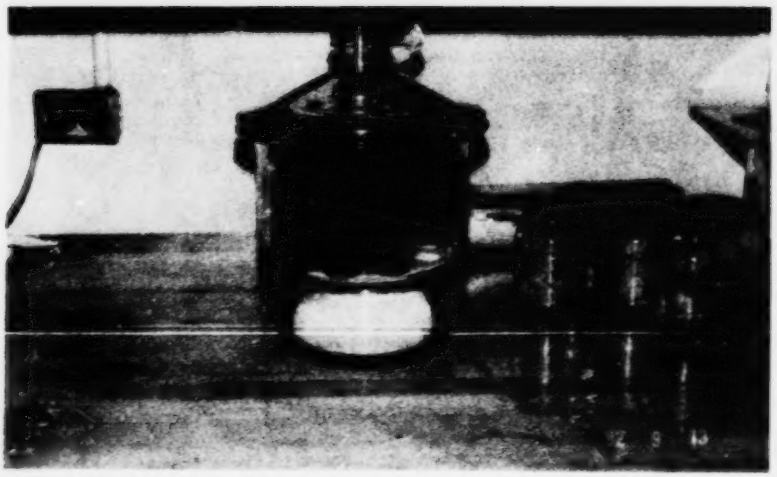


Fig. 11 - Desiccator.

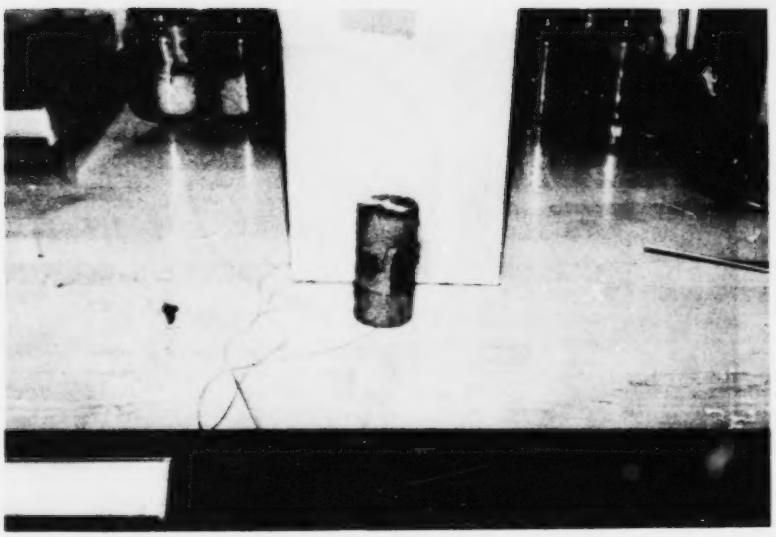


Fig. 12 - Strain ga d sample.

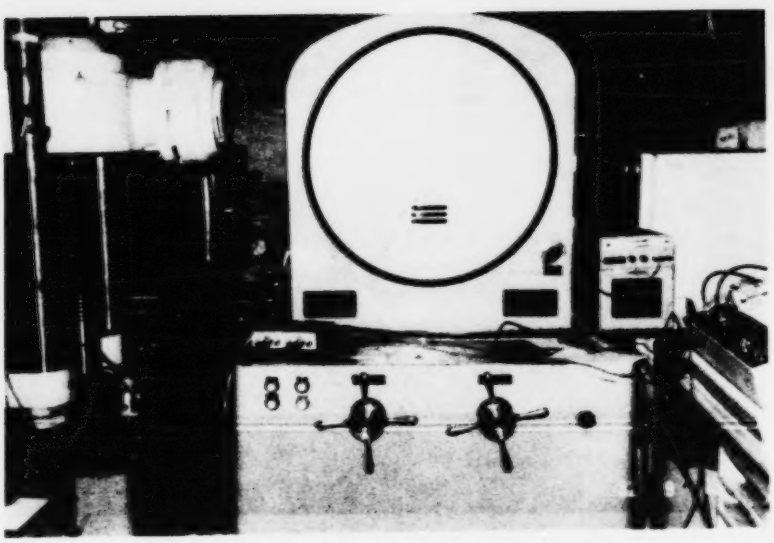


Fig. 13 - Compression testing machine.

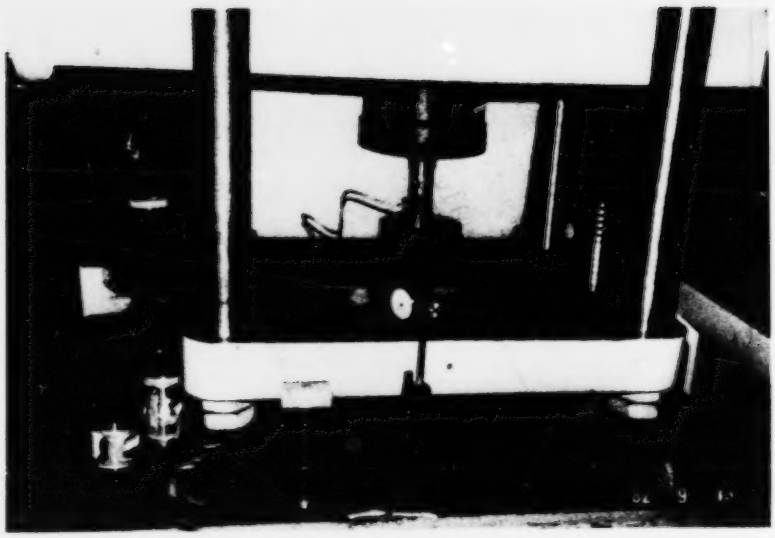


Fig. 14 - Press Stiffness measurements.

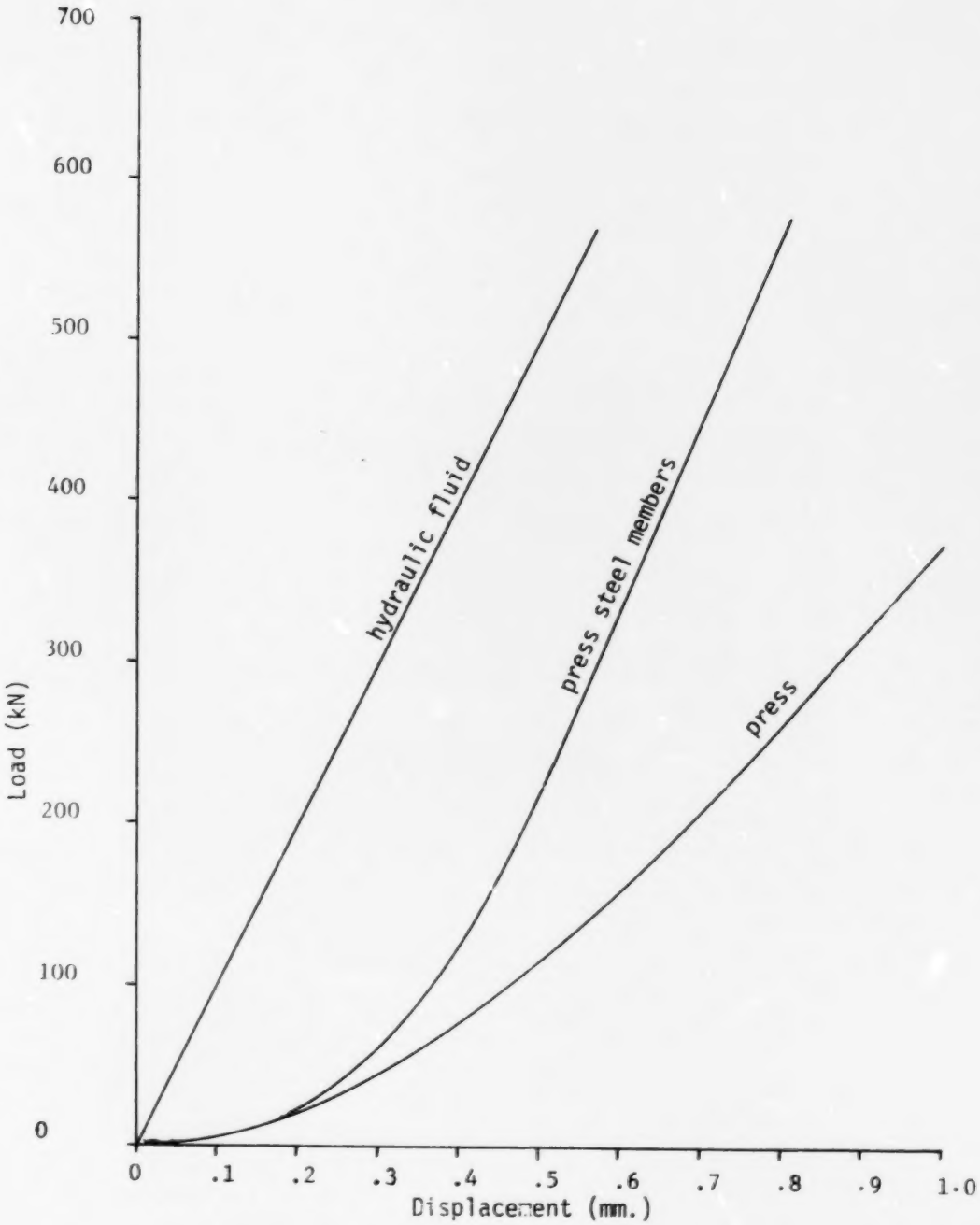


Fig.15 - Press stiffness plot

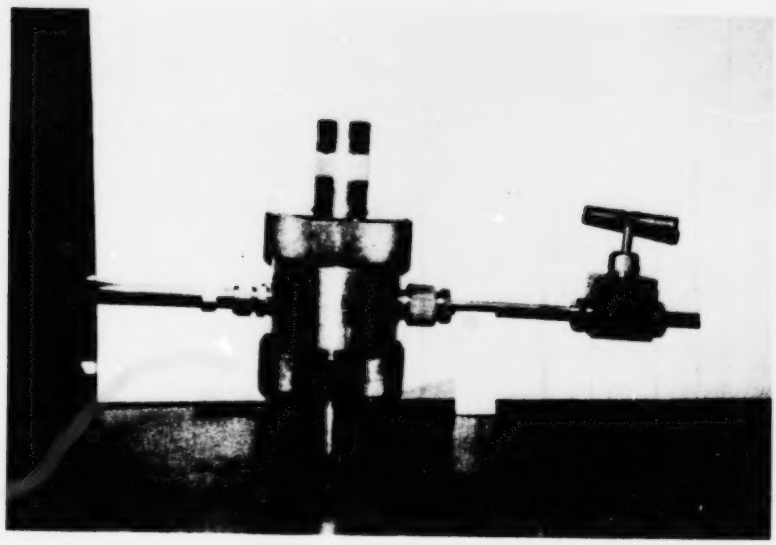


Fig. 16 - 'BX' Hoek Cell

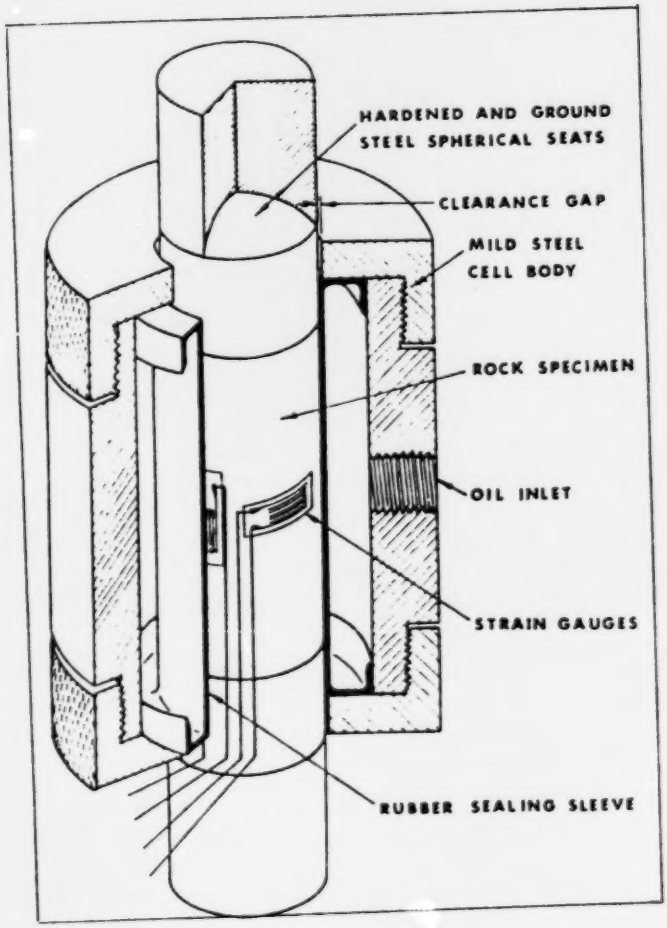


Fig. 17 - '3X' Hoek cell cut-away showing spherical seats.

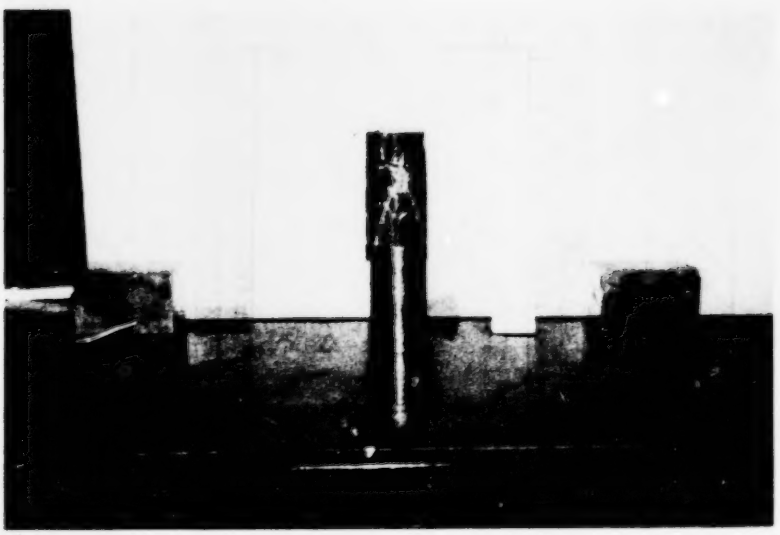


Fig. 18 - Failed sample showing sheared tip slippage.

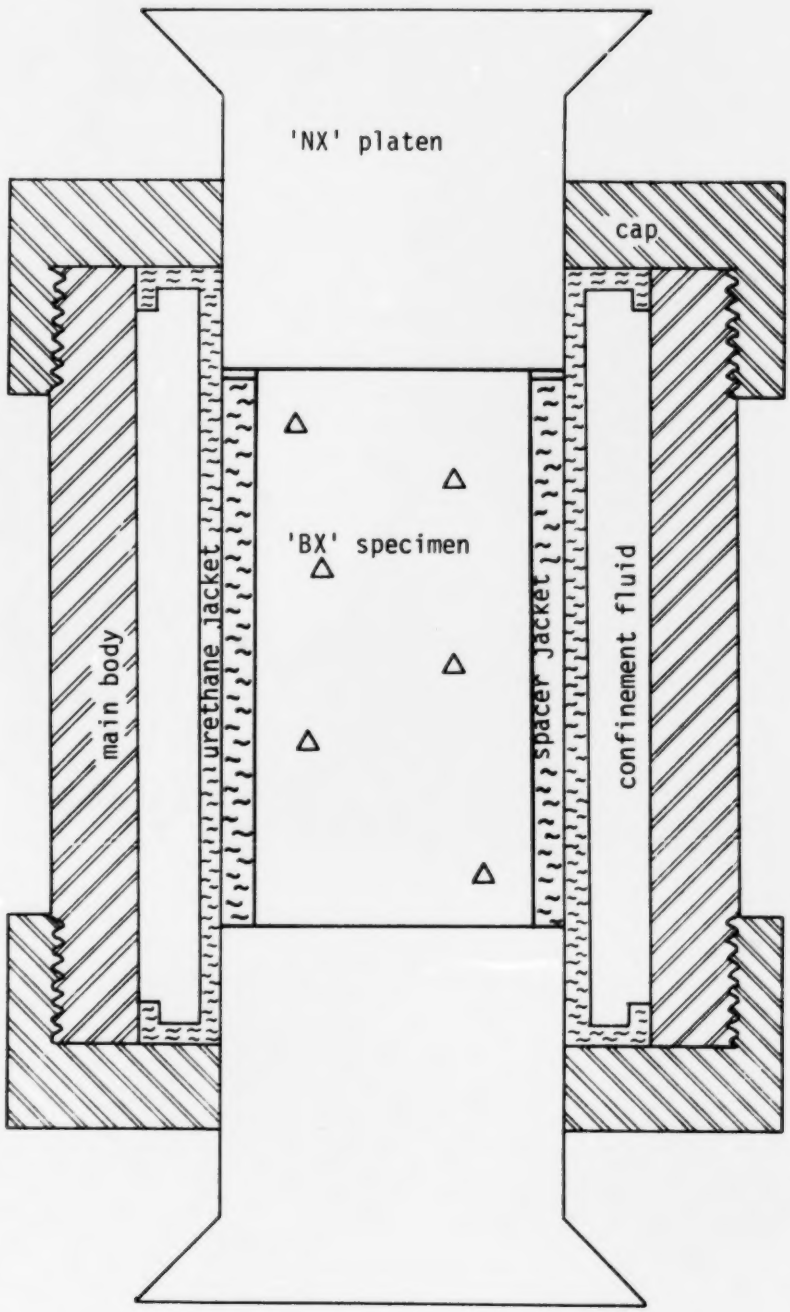


Fig. 19 - Cut-away of modified 'NX' hoek cell.

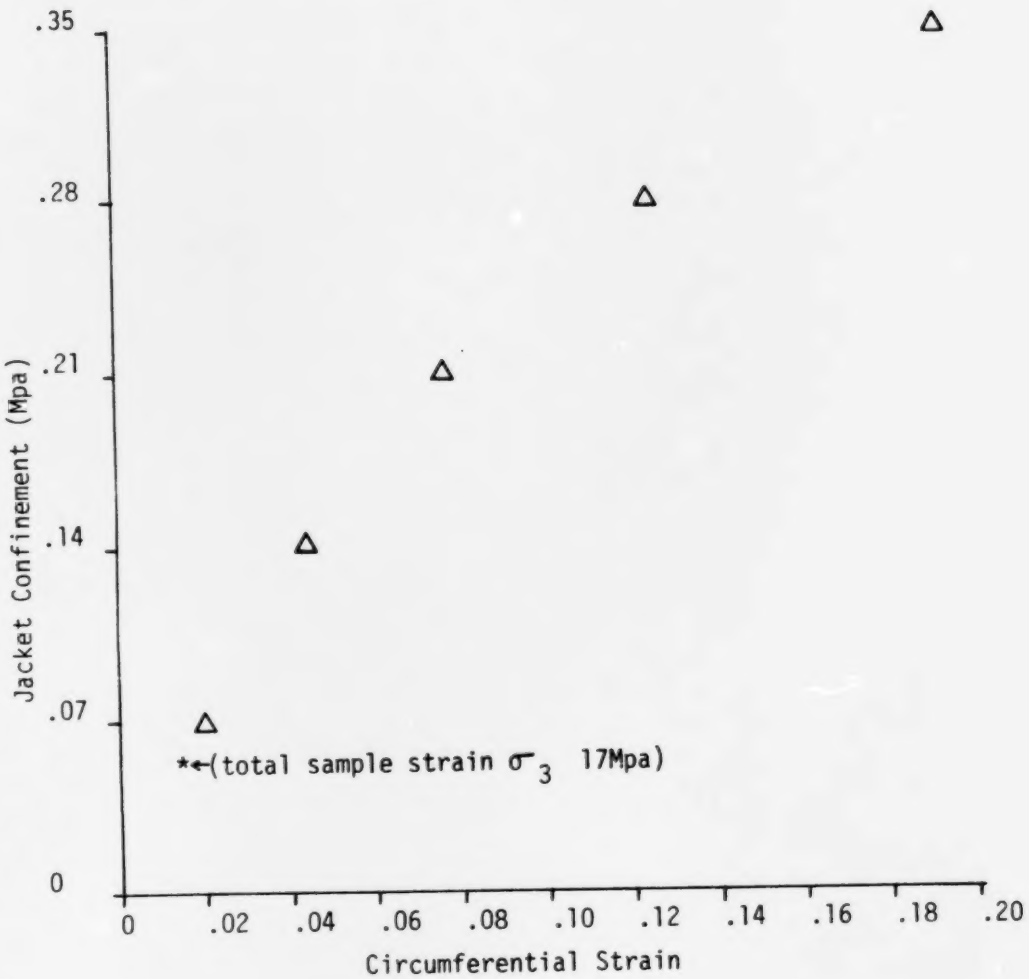


Fig. 20 - Calibration of urethane jacket.

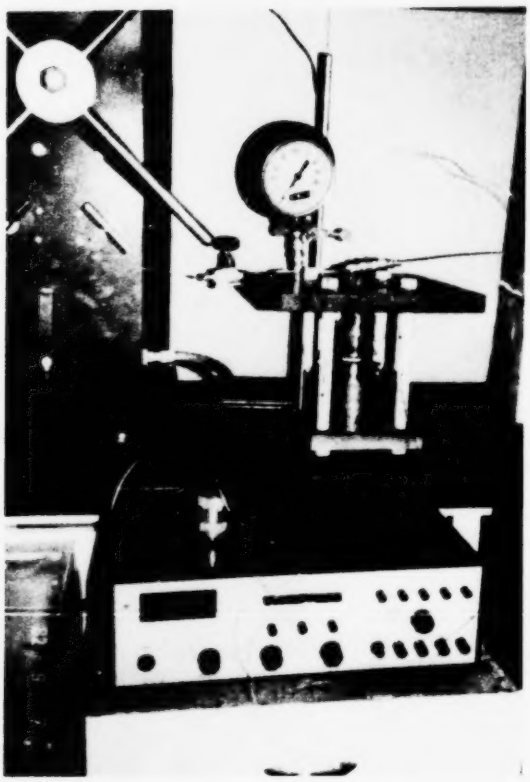


Fig. 21 - Urethane Jacket Calibration.

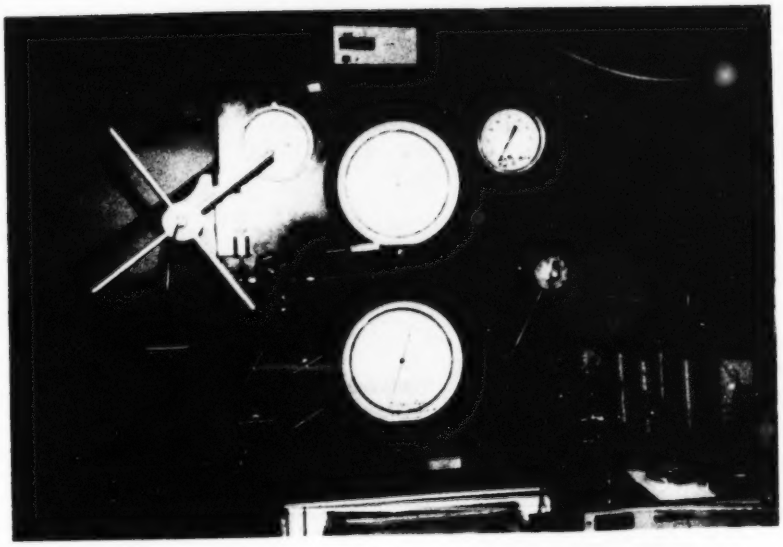


Fig. 22 - Confinement pressure panel.

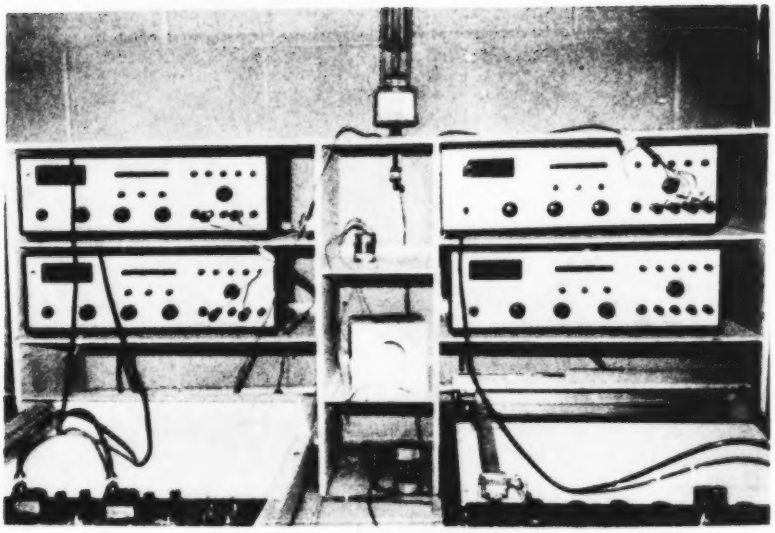


Fig. 23 - Strain indicators.

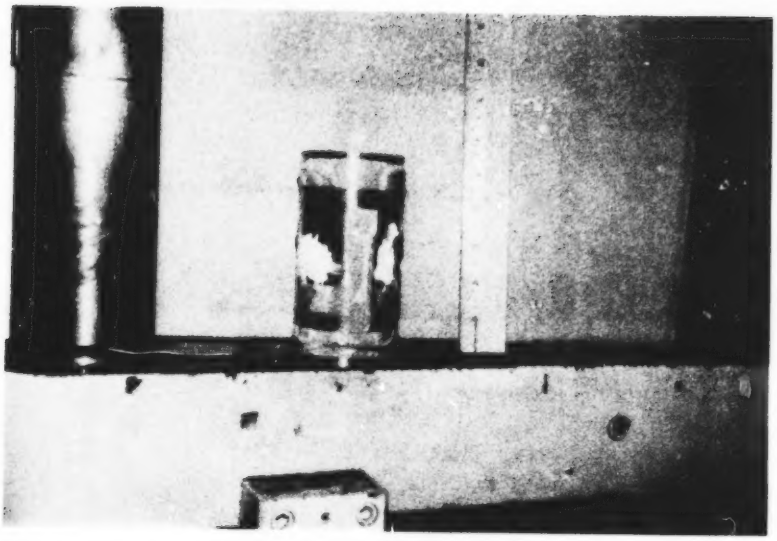


Fig. 24 - Load cell.

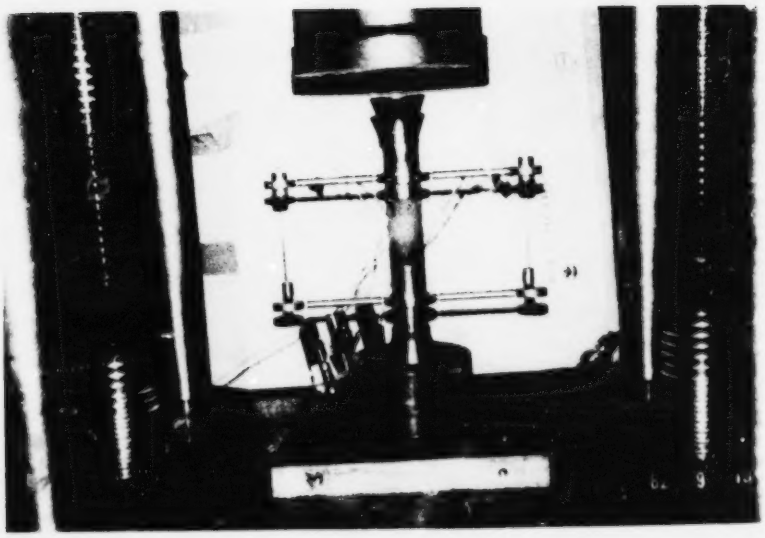


Fig. 25 - Displacement transducers.

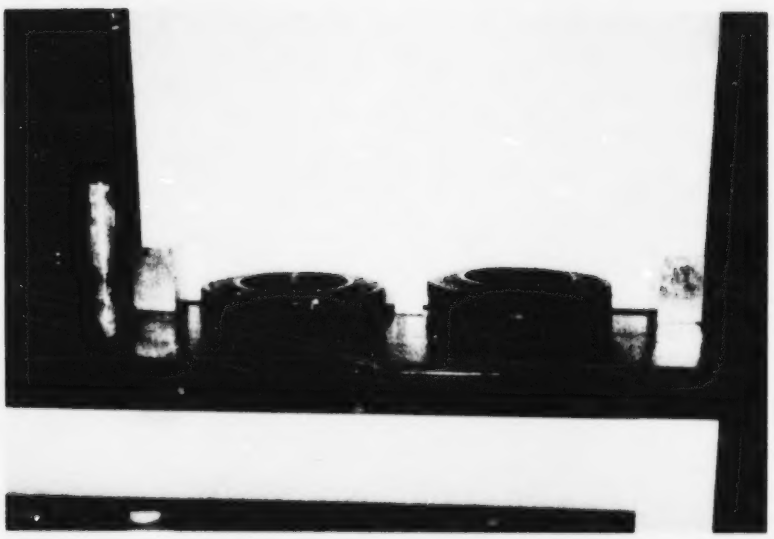


Fig. 26 - Schnorr disc springs.

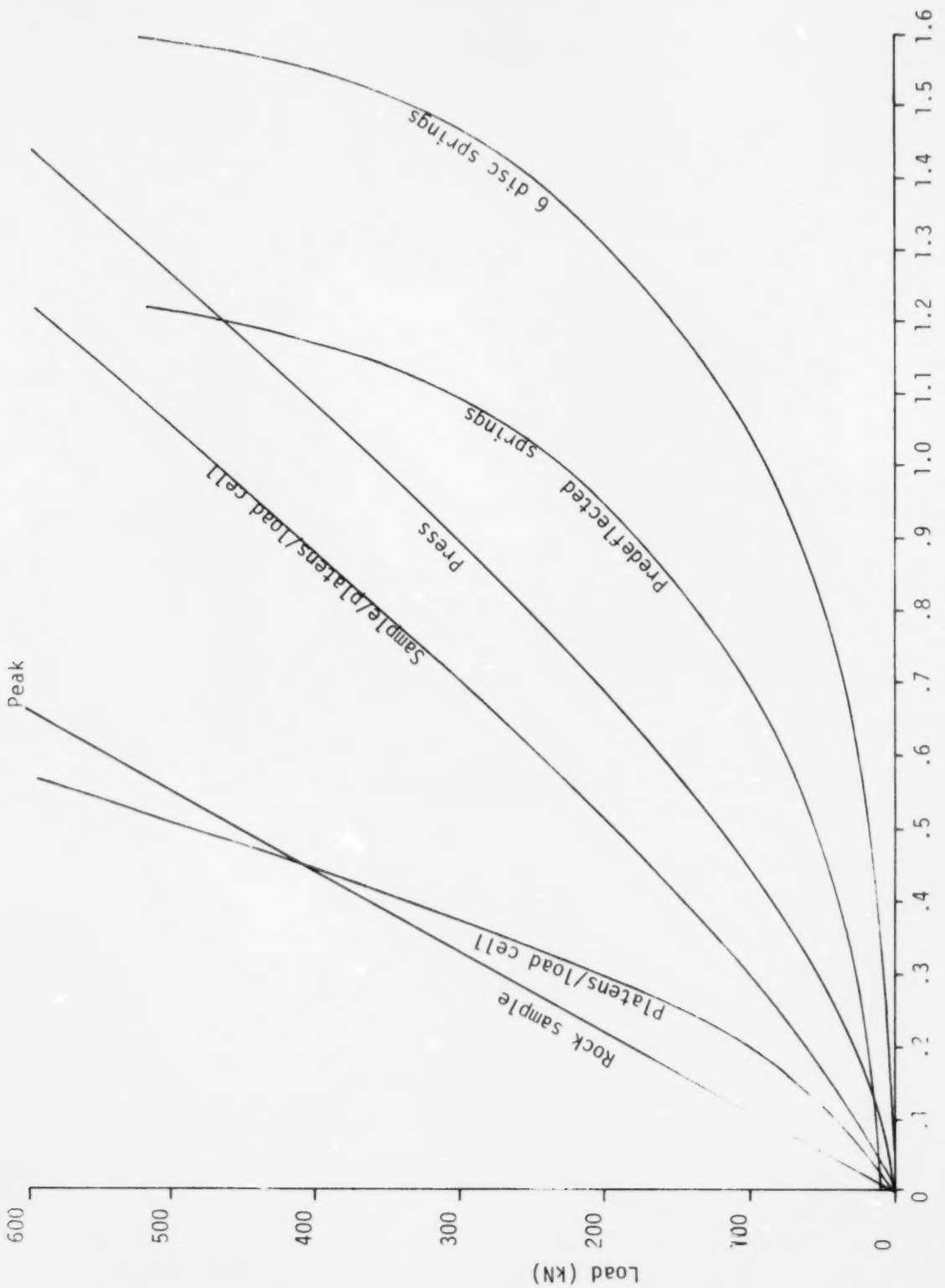


Fig. 27 - Component stiffness characteristics.

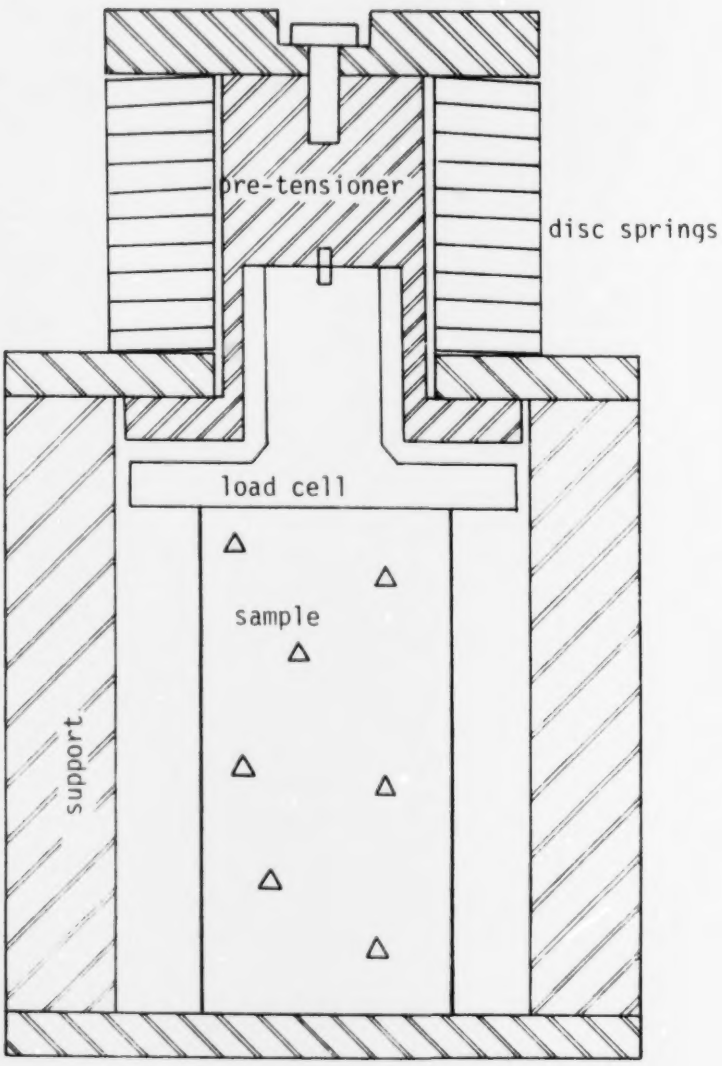


Fig. 28 - 18MN uniaxial stiff assembly.

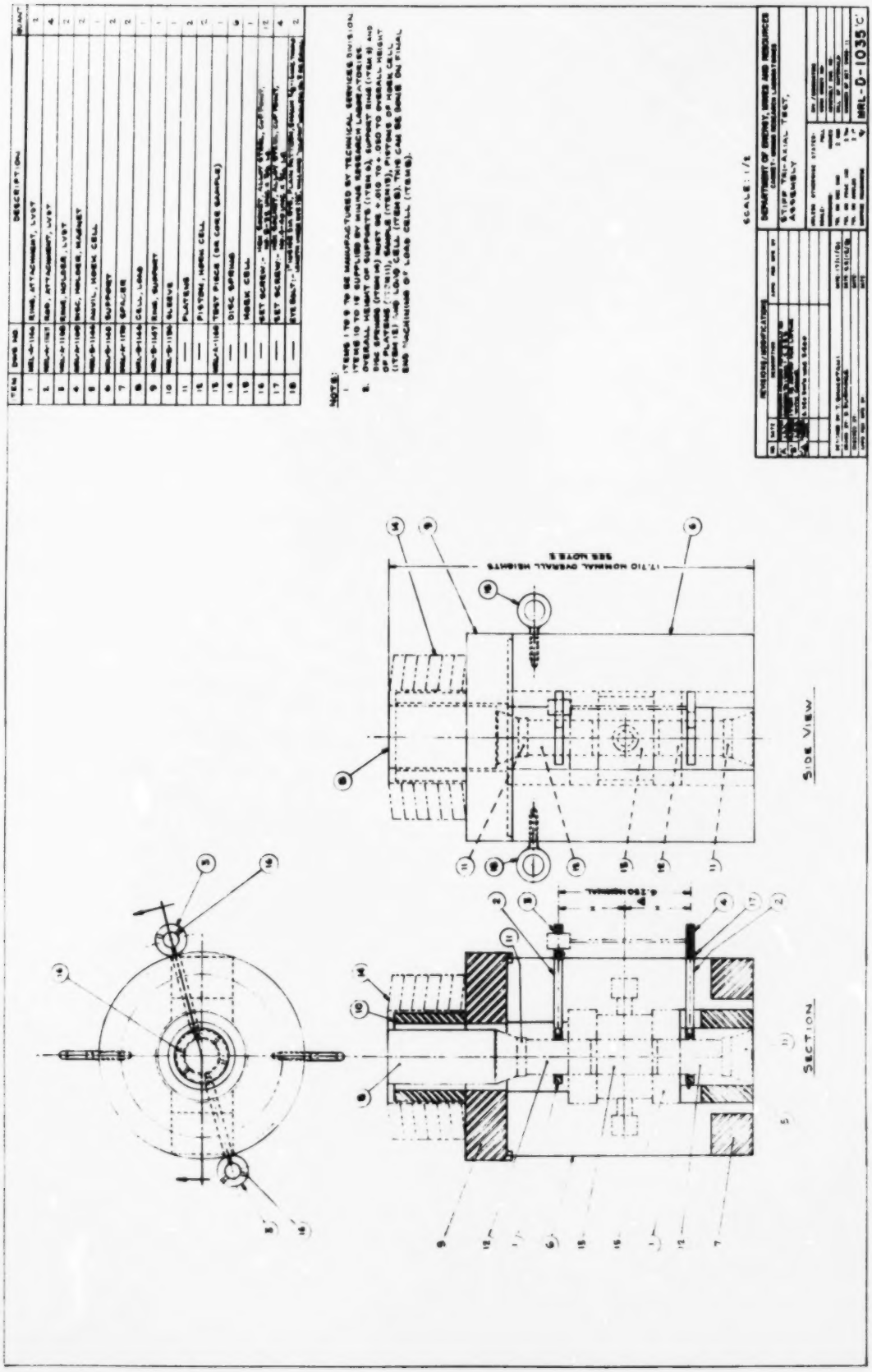


Fig. 29 - 'BX' triaxial stiff assembly.

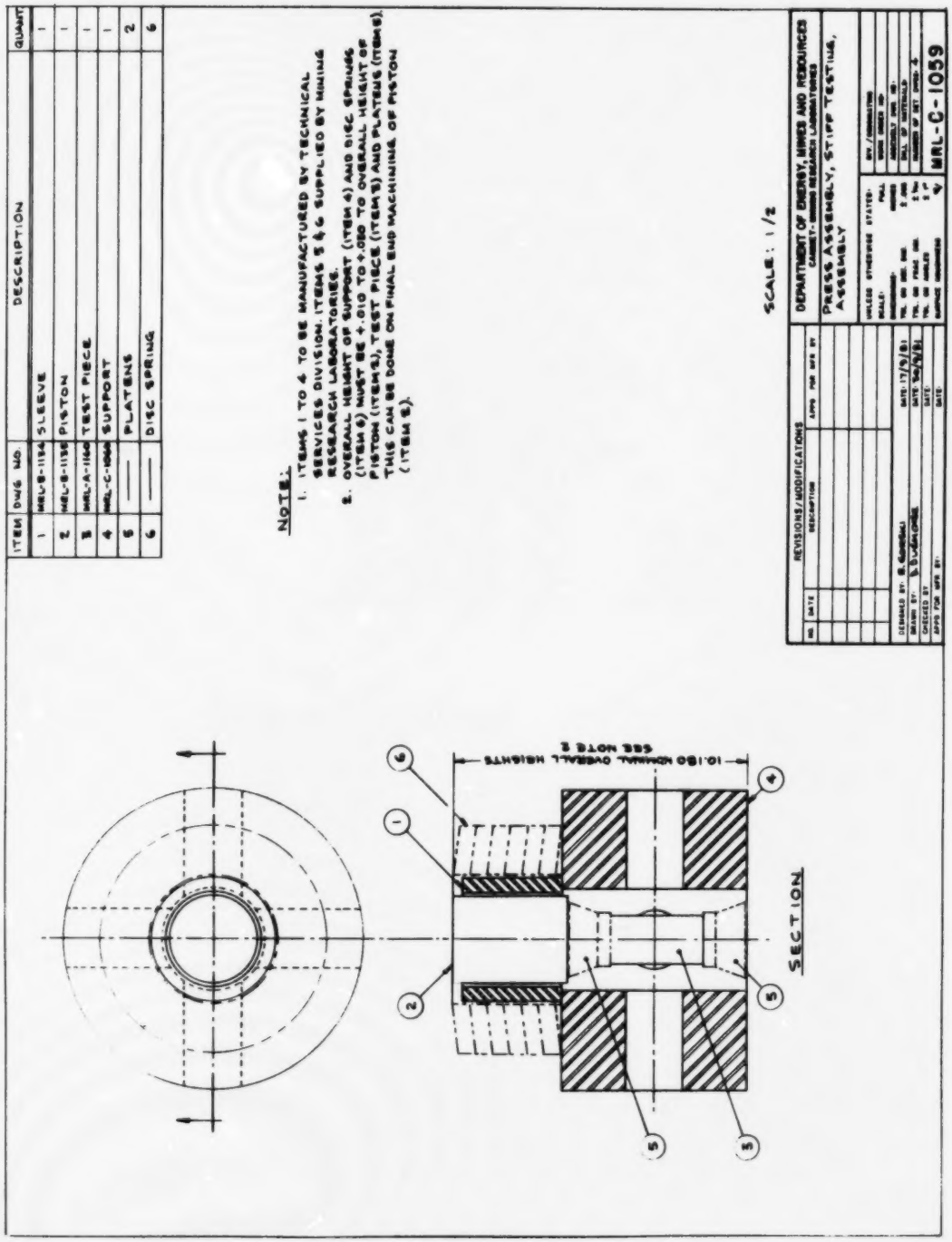
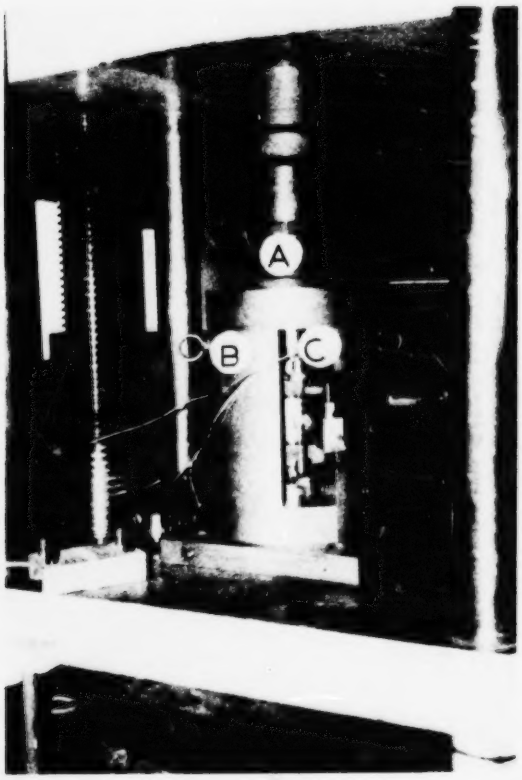

ITEM DWG NO. DESCRIPTION QUANT
1 MRL-B-1134 SLEEVE 1
2 MRL-B-1135 PISTON 1
3 MRL-A-1140 TEST PIECE 1
4 MRL-C-1060 SUPPORT 1
5 —— PLATENS 2
6 —— DISC SPRING 6
NOTE:
1. ITEMS 1 TO 4 TO BE MANUFACTURED BY TECHNICAL SERVICES DIVISION. ITEMS 5 & 6 SUPPLIED BY MINING RESEARCH LABORATORIES.
2. OVERALL HEIGHT OF SUPPORT (ITEM 4) AND DISC SPRINGS (ITEM 6) MUST BE +.010 TO +.020 TO OVERALL HEIGHT OF PISTON (ITEM2), TEST PIECE (ITEM3) AND PLATENS (ITEM5). THIS CAN BE DONE ON FINAL END MACHINING OF PISTON (ITEM 2).
SCALE: 1/2
SECTION
10.180 NOMINAL OVERALL HEIGHTS
SEE NOTE 2
REVISIONS/MODIFICATIONS
DEPARTMENT OF ENERGY, MINES AND RESOURCES
CANMET - MINING RESEARCH LABORATORIES
PRESS ASSEMBLY, STIFF TESTING, ASSEMBLY
MRL-C-1059

Fig. 30 - 'BX' uniaxial stiff assembly.



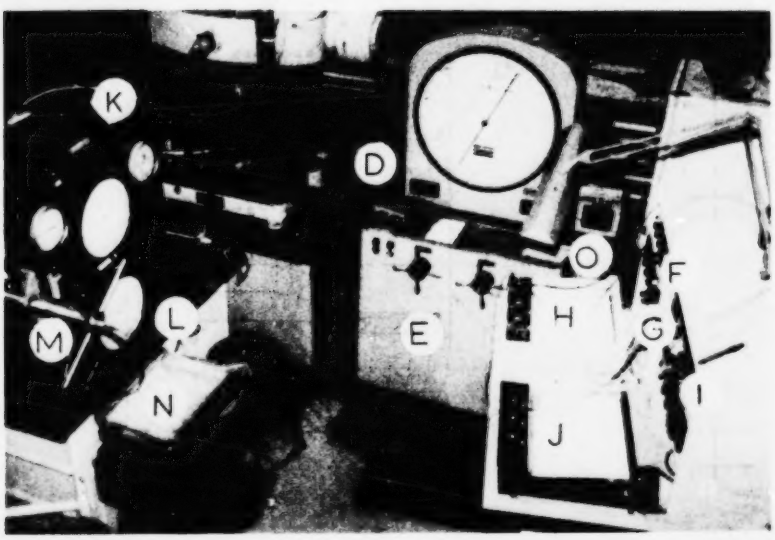


Fig. 31 - Physical test set-up.

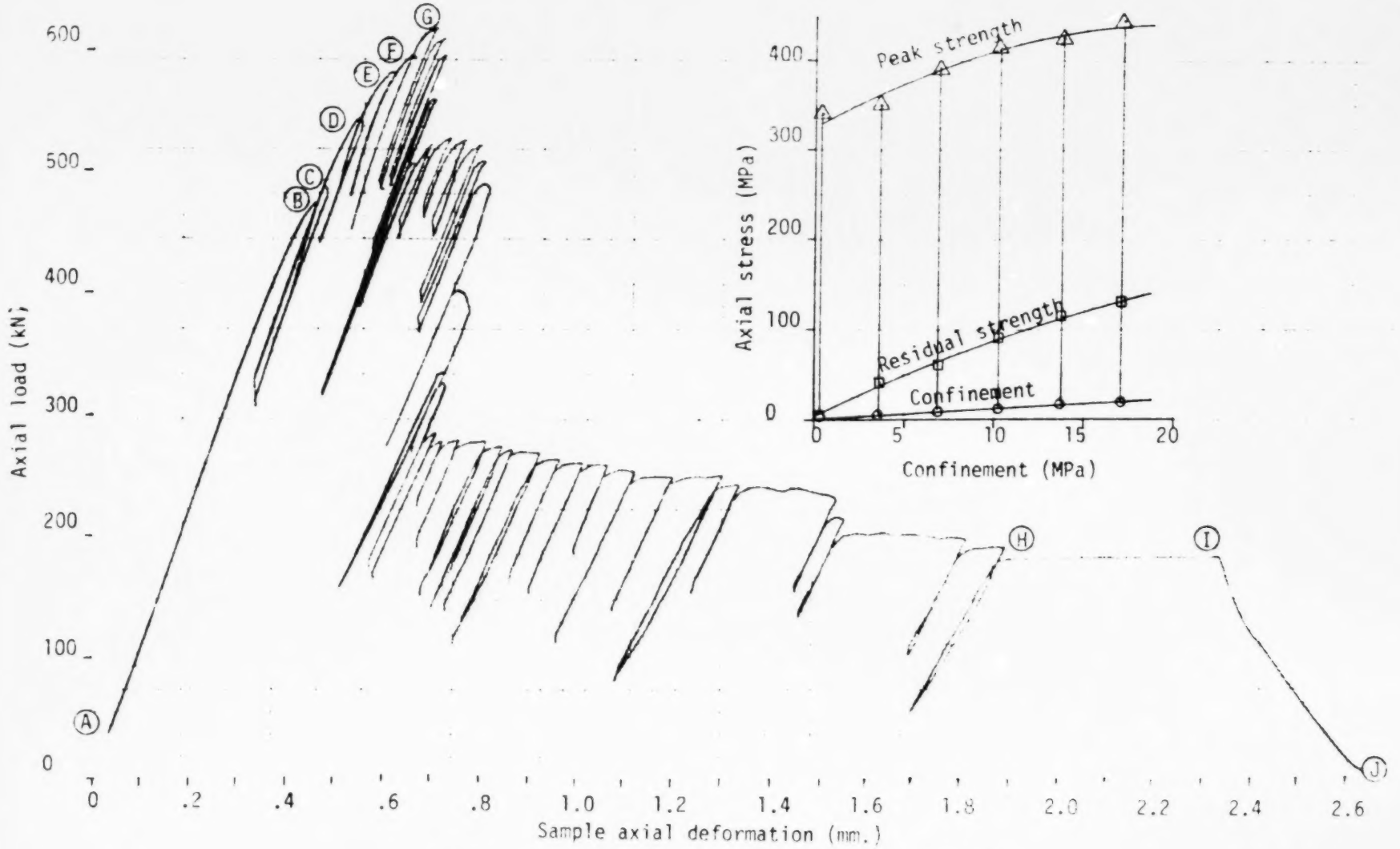


Fig. 32 - Multiple failure state stiff triaxial test.